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| 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 | 2045 | 2046 | 2047 | 2048 | 2049 | 2050 | 2051 | 2052 | 2053 | 2054 | 2055 | 2056 | 2057 | 2058 | 2059 | 2060 | 2061 | 2062 | 2063 | 2064 | 2065 | 2066 | 2067 | 2068 | 2069 | 2070 | 2071 | 2072 | 2073 | 2074 | 2075 | 2076 | 2077 | 2078 | 2079 | 2080 | 2081 | 2082 | 2083 | 2084 | 2085 | 2086 | 2087 | 2088 | 2089 | 2090 | 2091 | 2092 | 2093 | 2094 | 2095 | 2096 | 2097 | 2098 | 2099 | 2100 |      |

5           The present invention relates to mammalian cytokine receptor proteins with affinity for IL-13 (including without limitation human and murine receptor proteins), fragments thereof and recombinant polynucleotides and cells useful for expressing such proteins.

A variety of regulatory molecules, known as cytokines, have been identified including interleukin-13 (IL-13). Various protein forms of IL-13 and DNA encoding various forms of IL-13 activity are described in McKenzie et al., Proc. Natl. Acad. Sci. USA 90:3735 (1993); Minty et al., Nature 362:248 (1993); and Aversa et al., WO94/04680. Thus, the term "IL-13" includes proteins having the sequence and/or biological activity described in these documents, whether produced by recombinant genetic engineering techniques; purified from cell sources producing the factor naturally or upon induction with other factors; or synthesized by chemical techniques; or a combination of the foregoing.

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13R and the IL-4 receptor ("IL-4R") sharing a common component, which is required for receptor activation; however, IL-13 does not bind to cells transfected with the 130 kD IL-4R (Zurawski et al., *supra*). Thus, the IL-13R must contain at least one other ligand binding chain. Cytokine receptors are commonly composed or two or three chains. The cloning of one ligand binding chain for IL-13 has been recently reported (Hilton et al., Proc. Natl. Acad. Sci. 93:497-501).

It would be desirable to identify and clone the sequence for any other IL-13 binding chain of IL-13R so that IL-13R proteins can be produced for various reasons, including production of therapeutics and screening for inhibitors of IL-13 binding to the receptor and receptor signaling.

#### Summary of the Invention

In accordance with the present invention, polynucleotides encoding the IL-13 binding chains of the interleukin-13 receptor are disclosed, including without limitation those from the murine and human receptors. In certain embodiments, the invention provides an isolated polynucleotide comprising a nucleotide sequence selected from the group consisting of:

(a) the nucleotide sequence of SEQ ID NO:1 from nucleotide 256 to nucleotide 1404;

(b) the nucleotide sequence of SEQ ID NO:3 from nucleotide 103 to nucleotide 1242;

(c) a nucleotide sequence varying from the sequence of the nucleotide sequence specified in (a) or (b) as a result of degeneracy of the genetic code;

(d) a nucleotide sequence capable of hybridizing under stringent conditions to the nucleotide specified in (a) or (b);

(e) a nucleotide sequence encoding a species homologue of the sequence specified in (a) or (b); and

(f) an allelic variant of the nucleotide sequence specified in (a) or (b). Preferably, the nucleotide sequence encodes a protein having a biological activity of the human IL-13 receptor. The nucleotide sequence may be operably linked to an expression control sequence. In preferred embodiments, the polynucleotide

comprises the nucleotide sequence of SEQ ID NO:1 from nucleotide 256 to nucleotide 1404; the nucleotide sequence of SEQ ID NO:1 from nucleotide 319 to nucleotide 1257; the nucleotide sequence of SEQ ID NO:1 from nucleotide 1324 to nucleotide 1404; the nucleotide sequence of SEQ ID NO:3 from nucleotide 103 to nucleotide 1242; the nucleotide sequence of SEQ ID NO:3 from nucleotide 178 to nucleotide 1125; or the nucleotide sequence of SEQ ID NO:3 from nucleotide 1189 to nucleotide 1242.

The invention also provides isolated polynucleotides comprising a nucleotide sequence encoding a peptide or protein comprising an amino acid sequence selected from the group consisting of:

- (a) the amino acid sequence of SEQ ID NO:2;
- (b) the amino acid sequence of SEQ ID NO:2 from amino acids 22 to 334;
- (c) the amino acid sequence of SEQ ID NO:2 from amino acids 357 to 383;
- (d) the amino acid sequence of SEQ ID NO:4;
- (e) the amino acid sequence of SEQ ID NO:4 from amino acids 26 to 341;
- (f) the amino acid sequence of SEQ ID NO:4 from amino acids 363 to 380; and
- (g) fragments of (a)-(f) having a biological activity of the IL-13 receptor binding chain. Other preferred embodiments encode the amino acid sequence of SEQ ID NO:2 from amino acids 1 to 331 and the amino acid sequence of SEQ ID NO:2 from amino acids 26 to 331.

Host cells, preferably mammalian cells, transformed with the polynucleotides are also provided.

In other embodiments, the invention provides a process for producing a IL-13bc protein. The process comprises:

- (a) growing a culture of the host cell of the present invention in a suitable culture medium; and
- (b) purifying the human IL-13bc protein from the culture.

Proteins produced according to these methods are also provided.

The present invention also provides for an isolated IL-13bc protein comprising an amino acid sequence selected from the group consisting of:

- (a) the amino acid sequence of SEQ ID NO:2;
- 5 (b) the amino acid sequence of SEQ ID NO:2 from amino acids 22 to 334;
- (c) the amino acid sequence of SEQ ID NO:2 from amino acids 357 to 383;
- (d) the amino acid sequence of SEQ ID NO:4;
- 10 (e) the amino acid sequence of SEQ ID NO:4 from amino acids 26 to 341;
- (f) the amino acid sequence of SEQ ID NO:4 from amino acids 363 to 380; and
- (g) fragments of (a)-(f) having a biological activity of the IL-13  
15 receptor binding chain

Preferably the protein comprises the amino acid sequence of SEQ ID NO:2; the sequence from amino acid 22 to 334 of SEQ ID NO:2; the sequence of SEQ ID NO:4; or the sequence from amino acid 26 to 341 of SEQ ID NO:4. In other preferred embodiments, the specified amino acid sequence is part of a fusion  
20 protein (with an additional amino acid sequence not derived from IL-13bc). Preferred fusion proteins comprise an antibody fragment, such as an Fc fragment. Particularly preferred embodiments comprise the amino acid sequence of SEQ ID NO:2 from amino acids 1 to 331 and the amino acid sequence of SEQ ID NO:2 from amino acids 26 to 331.

25 Pharmaceutical compositions comprising a protein of the present invention and a pharmaceutically acceptable carrier are also provided.

The present invention further provides for compositions comprising an antibody which specifically reacts with a protein of the present invention.

30 Methods of identifying an inhibitor of IL-13 binding to the IL-13bc or IL-13 receptor are also provided. These methods comprise:

(a) combining an IL-13bc protein or a fragment thereof with IL-13 or a fragment thereof, said combination forming a first binding mixture;

(b) measuring the amount of binding between the protein and the IL-13 or fragment in the first binding mixture;

5 (c) combining a compound with the protein and the IL-13 or fragment to form a second binding mixture;

(d) measuring the amount of binding in the second binding mixture; and

(e) comparing the amount of binding in the first binding mixture with the amount of binding in the second binding mixture;

10 wherein the compound is capable of inhibiting IL-13 binding to the IL-13bc protein or IL-13 receptor when a decrease in the amount of binding of the second binding mixture occurs. Inhibitors of IL-13R identified by these methods and pharmaceutical compositions containing them are also provided.

15 Methods of inhibiting binding of IL-13 to the IL-13bc proteins or IL-13 receptor in a mammalian subject are also disclosed which comprise administering a therapeutically effective amount of a composition containing an IL-13bc protein, an IL-13bc or IL-13R inhibitor or an antibody to an IL-13bc protein.

20 ~~Methods are also provided for potentiating IL-13 activity, which comprise combining a protein having IL-13 activity with a protein of claim 11 and contacting such combination with a cell expressing at least one chain of IL-13R other than IL-13bc. Preferably, the contacting step is performed by administering a therapeutically effective amount of such combination to a mammalian subject.~~

#### Brief Description of the Figure

25 ~~The Figure presents photographs of IL-13, IL-4, IL-11 and mock transfected COS cells after exposure to IL-13bc-Fc as described in Example 4 below.~~

#### Detailed Description of Preferred Embodiments

30 The inventors of the present application have for the first time identified and provided polynucleotides encoding the IL-13 binding chain of IL-13R

(hereinafter "IL-13bc"), including without limitation polynucleotides encoding murine and human IL-13bc.

5  
Sub C3  
SEQ ID NO:1 provides the nucleotide sequence of a cDNA encoding the murine IL-13bc. SEQ ID NO:2 provides predicted the amino acid sequence of the receptor chain, including a putative signal sequence from amino acids 1-21. The mature murine IL-13bc is believed to have the sequence of amino acids 22-383 of SEQ ID NO:2. The mature murine receptor chain has at least three distinct domains: an extracellular domain (comprising approximately amino acids 22-334 of SEQ ID NO:2), a transmembrane domain (comprising approximately amino acids 335-356 of SEQ ID NO:2) and an intracellular domain (comprising approximately amino acids 357-383 of SEQ ID NO:2).

10  
15  
20  
SEQ ID NO:3 provides the nucleotide sequence of a cDNA encoding the human IL-13bc. SEQ ID NO:4 provides predicted the amino acid sequence of the receptor chain, including a putative signal sequence from amino acids 1-25. The mature human IL-13bc is believed to have the sequence of amino acids 26-380 of SEQ ID NO:4. The mature human receptor chain has at least three distinct domains: an extracellular domain (comprising approximately amino acids 26-341 of SEQ ID NO:4), a transmembrane domain (comprising approximately amino acids 342-362 of SEQ ID NO:4) and an intracellular domain (comprising approximately amino acids 363-380 of SEQ ID NO:4).

25  
The first 81 amino acids of the human IL-13bc sequence are identical to the translated sequence of an expressed sequence tag (EST) identified as "yg99f10.r1 Homo sapiens cDNA clone 41648 5'" and assigned database accession number R52795.gb\_est2. There are no homologies or sequence motifs in this EST sequence which would lead those skilled in the art to identify the encoded protein as a cytokine receptor.

30  
Soluble forms of IL-13bc protein can also be produced. Such soluble forms include without limitation proteins comprising amino acids 1-334 or 22-334 of SEQ ID NO:2 or amino acids 1-341 or 26-341 of SEQ ID NO:4. The soluble forms of the IL-13bc are further characterized by being soluble in aqueous solution, preferably at room temperature. IL-13bc proteins comprising only the intracellular

domain or a portion thereof may also be produced. Any forms of IL-13bc of less than full length are encompassed within the present invention and are referred to herein collectively with full length and mature forms as "IL-13bc" or "IL-13bc proteins." IL-13bc proteins of less than full length may be produced by expressing  
5 a corresponding fragment of the polynucleotide encoding the full-length IL-13bc protein (SEQ ID NO:1 or SEQ ID NO:3). These corresponding polynucleotide fragments are also part of the present invention. Modified polynucleotides as described above may be made by standard molecular biology techniques, including construction of appropriate desired deletion mutants, site-directed mutagenesis  
10 methods or by the polymerase chain reaction using appropriate oligonucleotide primers.

For the purposes of the present invention, a protein has "a biological activity of the IL-13 receptor binding chain" if it possess one or more of the following characteristics: (1) the ability to bind IL-13 or a fragment thereof  
15 (preferably a biologically active fragment thereof); and/or (2) the ability to interact with the second non-IL-13-binding chain of IL-13R to produce a signal characteristic of the binding of IL-13 to IL-13R. Preferably, the biological activity possessed by the protein is the ability to bind IL-13 or a fragment hereof, more preferably with a  $K_D$  of about 0.1 to about 100 nM. Methods for determining  
20 whether a particular protein or peptide has such activity include without limitation the methods described in the examples provided herein.

IL-13bc or active fragments thereof (IL-13bc proteins) may be fused to carrier molecules such as immunoglobulins. For example, soluble forms of the IL-13bc may be fused through "linker" sequences to the Fc portion of an  
25 immunoglobulin. Other fusions proteins, such as those with GST, Lex-A or MBP, may also be used.

The invention also encompasses allelic variants of the nucleotide sequences as set forth in SEQ ID NO:1 or SEQ ID NO:3, that is, naturally-occurring alternative forms of the isolated polynucleotide of SEQ ID NO:1 or SEQ ID NO:3  
30 which also encode IL-13bc proteins, preferably those proteins having a biological activity of IL-13bc. Also included in the invention are isolated polynucleotides

which hybridize to the nucleotide sequence set forth in SEQ ID NO:1 or SEQ ID NO:3 under highly stringent conditions (for example, 0.1xSSC at 65°C). Isolated polynucleotides which encode IL-13bc proteins but which differ from the nucleotide sequence set forth in SEQ ID NO:1 or SEQ ID NO:3 by virtue of the degeneracy of the genetic code are also encompassed by the present invention. Variations in the nucleotide sequence as set forth in SEQ ID NO:1 or SEQ ID NO:3 which are caused by point mutations or by induced modifications are also included in the invention.

The present invention also provides polynucleotides encoding homologues of the murine and human IL-13bc from other animal species, particularly other mammalian species. Species homologues can be identified and isolated by making probes or primers from the murine or human sequences disclosed herein and screening a library from an appropriate species, such as for example libraries constructed from PBMCs, thymus or testis of the relevant species.

The isolated polynucleotides of the invention may be operably linked to an expression control sequence such as the pMT2 or pED expression vectors disclosed in Kaufman et al., Nucleic Acids Res. 19, 4485-4490 (1991), in order to produce the IL-13bc protein recombinantly. Many suitable expression control sequences are known in the art. General methods of expressing recombinant proteins are also known and are exemplified in R. Kaufman, Methods in Enzymology 185, 537-566 (1990). As defined herein "operably linked" means enzymatically or chemically ligated to form a covalent bond between the isolated polynucleotide of the invention and the expression control sequence, in such a way that the IL-13bc protein is expressed by a host cell which has been transformed (transfected) with the ligated polynucleotide/expression control sequence.

A number of types of cells may act as suitable host cells for expression of the IL-13bc protein. Any cell type capable of expressing functional IL-13bc protein may be used. Suitable mammalian host cells include, for example, monkey COS cells, Chinese Hamster Ovary (CHO) cells, human kidney 293 cells, human epidermal A431 cells, human Colo205 cells, 3T3 cells, CV-1 cells, other transformed primate cell lines, normal diploid cells, cell strains derived from in



vitro culture of primary tissue, primary explants, HeLa cells, mouse L cells, BHK, HL-60, U937, HaK, Rat2, BaF3, 32D, FDCP-1, PC12, M1x or C2C12 cells.

5 The IL-13bc protein may also be produced by operably linking the isolated polynucleotide of the invention to suitable control sequences in one or more insect expression vectors, and employing an insect expression system. Materials and methods for baculovirus/insect cell expression systems are commercially available in kit form from, e.g., Invitrogen, San Diego, California, U.S.A. (the MaxBac® kit), and such methods are well known in the art, as described in Summers and Smith, Texas Agricultural Experiment Station Bulletin No. 1555 (1987),  
10 incorporated herein by reference. Soluble forms of the IL-13bc protein may also be produced in insect cells using appropriate isolated polynucleotides as described above.

Alternatively, the IL-13bc protein may be produced in lower eukaryotes such as yeast or in prokaryotes such as bacteria. Suitable yeast strains include  
15 *Saccharomyces cerevisiae*, *Schizosaccharomyces pombe*, *Kluyveromyces* strains, *Candida*, or any yeast strain capable of expressing heterologous proteins. Suitable bacterial strains include *Escherichia coli*, *Bacillus subtilis*, *Salmonella typhimurium*, or any bacterial strain capable of expressing heterologous proteins.

Expression in bacteria may result in formation of inclusion bodies  
20 incorporating the recombinant protein. Thus, refolding of the recombinant protein may be required in order to produce active or more active material. Several methods for obtaining correctly folded heterologous proteins from bacterial inclusion bodies are known in the art. These methods generally involve solubilizing the protein from the inclusion bodies, then denaturing the protein  
25 completely using a chaotropic agent. When cysteine residues are present in the primary amino acid sequence of the protein, it is often necessary to accomplish the refolding in an environment which allows correct formation of disulfide bonds (a redox system). General methods of refolding are disclosed in Kohno, Meth. Enzym., 185:187-195 (1990). EP 0433225 and copending application USSN  
30 08/163,877 describe other appropriate methods.

The IL-13bc protein of the invention may also be expressed as a product of transgenic animals, e.g., as a component of the milk of transgenic cows, goats, pigs, or sheep which are characterized by somatic or germ cells containing a polynucleotide sequence encoding the IL-13bc protein.

5           The IL-13bc protein of the invention may be prepared by growing a culture transformed host cells under culture conditions necessary to express the desired protein. The resulting expressed protein may then be purified from the culture medium or cell extracts. Soluble forms of the IL-13bc protein of the invention can be purified from conditioned media. Membrane-bound forms of IL-13bc protein  
10 of the invention can be purified by preparing a total membrane fraction from the expressing cell and extracting the membranes with a non-ionic detergent such as Triton X-100.

          The IL-13bc protein can be purified using methods known to those skilled in the art. For example, the IL-13bc protein of the invention can be concentrated  
15 using a commercially available protein concentration filter, for example, an Amicon or Millipore Pellicon ultrafiltration unit. Following the concentration step, the concentrate can be applied to a purification matrix such as a gel filtration medium. Alternatively, an anion exchange resin can be employed, for example, a matrix or substrate having pendant diethylaminoethyl (DEAE) or  
20 polyethyleimine (PEI) groups. The matrices can be acrylamide, agarose, dextran, cellulose or other types commonly employed in protein purification. Alternatively, a cation exchange step can be employed. Suitable cation exchangers include various insoluble matrices comprising sulfopropyl or carboxymethyl groups. Sulfopropyl groups are preferred (e.g., S-Sepharose® columns). The  
25 purification of the IL-13bc protein from culture supernatant may also include one or more column steps over such affinity resins as concanavalin A-agarose, heparin-toyopearl® or Cibacrom blue 3GA Sepharose®; or by hydrophobic interaction chromatography using such resins as phenyl ether, butyl ether, or propyl ether; or by immunoaffinity chromatography. Finally, one or more reverse-phase high  
30 performance liquid chromatography (RP-HPLC) steps employing hydrophobic RP-HPLC media, e.g., silica gel having pendant methyl or other aliphatic groups, can

be employed to further purify the IL-13bc protein. Affinity columns including IL-13 or fragments thereof or including antibodies to the IL-13bc protein can also be used in purification in accordance with known methods. Some or all of the foregoing purification steps, in various combinations or with other known methods, can also be employed to provide a substantially purified isolated recombinant protein. Preferably, the isolated IL-13bc protein is purified so that it is substantially free of other mammalian proteins.

IL-13bc proteins of the invention may also be used to screen for agents which are capable of binding to IL-13bc or IL-13R or which interfere with the binding of IL-13 to the IL-13 or IL-13bc (either the extracellular or intracellular domains) and thus may act as inhibitors of normal binding and cytokine action ("IL-13R inhibitors"). Binding assays using a desired binding protein, immobilized or not, are well known in the art and may be used for this purpose using the IL-13bc protein of the invention. Purified cell based or protein based (cell free) screening assays may be used to identify such agents. For example, IL-13bc protein may be immobilized in purified form on a carrier and binding to purified IL-13bc protein may be measured in the presence and in the absence of potential inhibiting agents. A suitable binding assay may alternatively employ a soluble form of IL-13bc of the invention. Another example of a system in which inhibitors may be screened is described in Example 2 below.

In such a screening assay, a first binding mixture is formed by combining IL-13 or a fragment thereof and IL-13bc protein, and the amount of binding in the first binding mixture ( $B_0$ ) is measured. A second binding mixture is also formed by combining IL-13 or a fragment thereof, IL-13bc protein, and the compound or agent to be screened, and the amount of binding in the second binding mixture (B) is measured. The amounts of binding in the first and second binding mixtures are compared, for example, by performing a calculation of the ratio  $B/B_0$ . A compound or agent is considered to be capable of inhibiting binding if a decrease in binding in the second binding mixture as compared to the first binding mixture is observed. Optionally, the second chain of IL-13R can be added to one or both of the binding mixtures. The formulation and optimization of binding mixtures is

within the level of skill in the art, such binding mixtures may also contain buffers and salts necessary to enhance or to optimize binding, and additional control assays may be included in the screening assay of the invention.

5       Compounds found to reduce the binding activity of IL-13bc protein to IL-13 or its fragment to any degree, preferably by at least about 10%, more preferably greater than about 50% or more, may thus be identified and then secondarily screened in other binding assays and in vivo assays. By these means compounds having inhibitory activity for IL-13bc binding which may be suitable as therapeutic agents may be identified.

10       IL-13bc proteins, and polynucleotides encoding them, may also be used as diagnostic agents for detecting the expression or presence of IL-13bc, IL-13R, IL-13 or cells expressing IL-13bc, IL-13R or IL-13. The proteins or polynucleotides may be employed for such purpose in standard procedures for diagnostics assays using these types of materials. Suitable methods are well known to those skilled  
15       in the art.

IL-13bc acts as a mediator of the known biological activities of IL-13. As a result, IL-13bc protein (particularly, soluble IL-13bc proteins) and IL-13R inhibitors may be useful in treatment or modulation of various medical conditions in which IL-13 is implicated or which are effected by the activity (or lack thereof)  
20       of IL-13 (collectively "IL-13-related conditions"). IL-13-related conditions include without limitation Ig-mediated conditions and diseases, particularly IgE-mediated conditions (including without limitation allergic conditions, asthma, immune complex diseases (such as, for example, lupus, nephrotic syndrome, nephritis, glomerulonephritis, thyroiditis and Grave's disease)); immune deficiencies,  
25       specifically deficiencies in hematopoietic progenitor cells, or disorders relating thereto; cancer and other disease. Such pathological states may result from disease, exposure to radiation or drugs, and include, for example, leukopenia, bacterial and viral infections, anemia, B cell or T cell deficiencies such as immune cell or hematopoietic cell deficiency following a bone marrow transplantation. Since IL-  
30       12 inhibits macrophage activation, IL-13bc proteins may also be useful to enhance

macrophage activation (i.e., in vaccination, treatment of mycobacterial or intracellular organisms, or parasitic infections).

IL-13bc proteins may also be used to potentiate the effects of IL-13 in vitro and in vivo. For example, an IL-13bc protein can be combined with a protein  
5 having IL-13 activity (preferably IL-13) and the resulting combination can be contacted with a cell expressing at least one chain of IL-13R other than IL-13bc (preferably all chains of IL-13R other than IL-13bc). Preferably, the contacting step is performed by administering a therapeutically effective amount of such combination to a mammalian subject in vivo. The pre-established association of  
10 the IL-13 protein with the IL-13bc protein will aid in formation of the complete IL-13/IL-13R complex necessary for proper signaling. See for example the methods described by Economides et al., Science 270:1351 (1995).

IL-13bc protein and IL-13R inhibitors, purified from cells or recombinantly produced, may be used as a pharmaceutical composition when combined with a  
15 pharmaceutically acceptable carrier. Such a composition may contain, in addition to IL-13bc or inhibitor and carrier, various diluents, fillers, salts, buffers, stabilizers, solubilizers, and other materials well known in the art. The term "pharmaceutically acceptable" means a non-toxic material that does not interfere with the effectiveness of the biological activity of the active ingredient(s). The  
20 characteristics of the carrier will depend on the route of administration.

The pharmaceutical composition of the invention may also contain cytokines, lymphokines, or other hematopoietic factors such as M-CSF, GM-CSF, IL-1, IL-2, IL-3, IL-4, IL-5, IL-6, IL-7, IL-8, IL-9, IL-10, IL-11, IL-12, IL-14, IL-15, G-CSF, stem cell factor, and erythropoietin. The pharmaceutical composition  
25 may also include anti-cytokine antibodies. The pharmaceutical composition may contain thrombolytic or anti-thrombotic factors such as plasminogen activator and Factor VIII. The pharmaceutical composition may further contain other anti-inflammatory agents. Such additional factors and/or agents may be included in the pharmaceutical composition to produce a synergistic effect with isolated IL-13bc  
30 protein or IL-13bc inhibitor, or to minimize side effects caused by the isolated IL-13bc or IL-13bc inhibitor. Conversely, isolated IL-13bc or IL-13bc inhibitor may

be included in formulations of the particular cytokine, lymphokine, other hematopoietic factor, thrombolytic or anti-thrombotic factor, or anti-inflammatory agent to minimize side effects of the cytokine, lymphokine, other hematopoietic factor, thrombolytic or anti-thrombotic factor, or anti-inflammatory agent.

5           The pharmaceutical composition of the invention may be in the form of a liposome in which isolated IL-13bc protein or IL-13bc inhibitor is combined, in addition to other pharmaceutically acceptable carriers, with amphipathic agents such as lipids which exist in aggregated form as micelles, insoluble monolayers, liquid crystals, or lamellar layers which in aqueous solution. Suitable lipids for  
10       liposomal formulation include, without limitation, monoglycerides, diglycerides, sulfatides, lysolecithin, phospholipids, saponin, bile acids, and the like. Preparation of such liposomal formulations is within the level of skill in the art, as disclosed, for example, in U.S. Patent No. 4,235,871; U.S. Patent No. 4,501,728; U.S. Patent No. 4,837,028; and U.S. Patent No. 4,737,323, all of which are  
15       incorporated herein by reference.

          As used herein, the term "therapeutically effective amount" means the total amount of each active component of the pharmaceutical composition or method that is sufficient to show a meaningful patient benefit, e.g., amelioration of symptoms of, healing of, or increase in rate of healing of such conditions. When  
20       applied to an individual active ingredient, administered alone, the term refers to that ingredient alone. When applied to a combination, the term refers to combined amounts of the active ingredients that result in the therapeutic effect, whether administered in combination, serially or simultaneously.

          In practicing the method of treatment or use of the present invention, a  
25       therapeutically effective amount of isolated IL-13bc protein or IL-13bc inhibitor is administered to a mammal. Isolated IL-13bc protein or IL-13bc inhibitor may be administered in accordance with the method of the invention either alone or in combination with other therapies such as treatments employing cytokines, lymphokines or other hematopoietic factors. When co-administered with one or  
30       more cytokines, lymphokines or other hematopoietic factors, IL-13bc protein or IL-13bc inhibitor may be administered either simultaneously with the cytokine(s),

lymphokine(s), other hematopoietic factor(s), thrombolytic or anti-thrombotic factors, or sequentially. If administered sequentially, the attending physician will decide on the appropriate sequence of administering IL-13bc protein or IL-13bc inhibitor in combination with cytokine(s), lymphokine(s), other hematopoietic factor(s), thrombolytic or anti-thrombotic factors.

Administration of IL-13bc protein or IL-13bc inhibitor used in the pharmaceutical composition or to practice the method of the present invention can be carried out in a variety of conventional ways, such as oral ingestion, inhalation, or cutaneous, subcutaneous, or intravenous injection. Intravenous administration to the patient is preferred.

When a therapeutically effective amount of IL-13bc protein or IL-13bc inhibitor is administered orally, IL-13bc protein or IL-13bc inhibitor will be in the form of a tablet, capsule, powder, solution or elixir. When administered in tablet form, the pharmaceutical composition of the invention may additionally contain a solid carrier such as a gelatin or an adjuvant. The tablet, capsule, and powder contain from about 5 to 95% IL-13bc protein or IL-13bc inhibitor, and preferably from about 25 to 90% IL-13bc protein or IL-13bc inhibitor. When administered in liquid form, a liquid carrier such as water, petroleum, oils of animal or plant origin such as peanut oil, mineral oil, soybean oil, or sesame oil, or synthetic oils may be added. The liquid form of the pharmaceutical composition may further contain physiological saline solution, dextrose or other saccharide solution, or glycols such as ethylene glycol, propylene glycol or polyethylene glycol. When administered in liquid form, the pharmaceutical composition contains from about 0.5 to 90% by weight of IL-13bc protein or IL-13bc inhibitor, and preferably from about 1 to 50% IL-13bc protein or IL-13bc inhibitor.

When a therapeutically effective amount of IL-13bc protein or IL-13bc inhibitor is administered by intravenous, cutaneous or subcutaneous injection, IL-13bc protein or IL-13bc inhibitor will be in the form of a pyrogen-free, parenterally acceptable aqueous solution. The preparation of such parenterally acceptable protein solutions, having due regard to pH, isotonicity, stability, and the like, is within the skill in the art. A preferred pharmaceutical composition for intravenous,

cutaneous, or subcutaneous injection should contain, in addition to IL-13bc protein or IL-13bc inhibitor an isotonic vehicle such as Sodium Chloride Injection, Ringer's Injection, Dextrose Injection, Dextrose and Sodium Chloride Injection, Lactated Ringer's Injection, or other vehicle as known in the art. The pharmaceutical composition of the present invention may also contain stabilizers, preservatives, buffers, antioxidants, or other additive known to those of skill in the art.

The amount of IL-13bc protein or IL-13bc inhibitor in the pharmaceutical composition of the present invention will depend upon the nature and severity of the condition being treated, and on the nature of prior treatments which the patient has undergone. Ultimately, the attending physician will decide the amount of IL-13bc protein or IL-13bc inhibitor with which to treat each individual patient. Initially, the attending physician will administer low doses of IL-13bc protein or IL-13bc inhibitor and observe the patient's response. Larger doses of IL-13bc protein or IL-13bc inhibitor may be administered until the optimal therapeutic effect is obtained for the patient, and at that point the dosage is not generally increased further. It is contemplated that the various pharmaceutical compositions used to practice the method of the present invention should contain about 0.1  $\mu$ g to about 100 mg of IL-13bc protein or IL-13bc inhibitor per kg body weight.

The duration of intravenous therapy using the pharmaceutical composition of the present invention will vary, depending on the severity of the disease being treated and the condition and potential idiosyncratic response of each individual patient. It is contemplated that the duration of each application of the IL-13bc protein or IL-13bc inhibitor will be in the range of 12 to 24 hours of continuous intravenous administration. Ultimately the attending physician will decide on the appropriate duration of intravenous therapy using the pharmaceutical composition of the present invention.

IL-13bc proteins of the invention may also be used to immunize animals to obtain polyclonal and monoclonal antibodies which specifically react with the IL-13bc protein and which may inhibit binding of IL-13 or fragments thereof to the receptor. Such antibodies may be obtained using the entire IL-13bc as an



immunogen, or by using fragments of IL-13bc, such as the soluble mature IL-13bc. Smaller fragments of the IL-13bc may also be used to immunize animals. The peptide immunogens additionally may contain a cysteine residue at the carboxyl terminus, and are conjugated to a hapten such as keyhole limpet hemocyanin (KLH). Additional peptide immunogens may be generated by replacing tyrosine residues with sulfated tyrosine residues. Methods for synthesizing such peptides are known in the art, for example, as in R.P. Merrifield, J.Amer.Chem.Soc. 85, 2149-2154 (1963); J.L. Krstenansky, et al., FEBS Lett. 211, 10 (1987).

Neutralizing or non-neutralizing antibodies (preferably monoclonal antibodies) binding to IL-13bc protein may also be useful therapeutics for certain tumors and also in the treatment of conditions described above. These neutralizing monoclonal antibodies may be capable of blocking IL-13 binding to the IL-13bc.

#### Example 1

##### Isolation of IL-13bc cDNAs

##### Isolation of the murine IL-13 receptor chain.

5 ug of polyA<sup>+</sup> RNA was prepared from the thymuses of 6-8 week old C3H/HeJ mice. Double stranded, hemimethylated cDNA was prepared using Stratagene's cDNA synthesis kit according to manufacturers instructions. Briefly, the first strand was primed with an oligodT-Xho primer, and after second strand synthesis, EcoRI adapters were added, and the cDNA was digested with XhoI, and purified. The cDNA was ligated to the XhoI-EcoRI sites of the Zap Express (Stratagene) lambda vector, and packaged using Gigapak II Gold packaging extracts (Stratagene) according to the manufacturers instructions. A library of 1.5 x 10<sup>6</sup> resulting recombinant phage was amplified following manufacturer's instructions. This library was screened with a degenerate 17mer oligonucleotide probe of the sequence KSRCTCCABK CRCTCCA (SEQ ID NO:5) (K = G+T; S = C+G; R = A+G; B = C+G+T) using standard TMAC hybridization conditions as described (Current Protocols in Molecular Biology, Ausubel, et al., editors., John Wiley and Sons, 1995, section 6.4.3). Clone A25 was identified because it hybridized to the 17mer probe, but not to probes derived from known

hematopoietin receptors. This clone was isolated in plasmid form from the ZapExpress vector as per manufacturers instruction, and the DNA sequence was determined. The DNA sequence encoded a novel member of the hematopoietin receptor family.

5            Clone A25 containing the polynucleotide having the sequence of SEQ ID NO:1 was deposited with ATCC as pA25pBKCMV at accession number \_\_\_\_\_ on February 22, 1996.

Isolation of the human IL-13 receptor chain.

10            A partial fragment of the human homolog of the murine receptor was isolated by PCR using oligonucleotides derived from the murine sequence. cDNA was prepared from human testis polyA+ RNA that was obtained from Clontech. A DNA fragment of 274 base pairs was amplified from this cDNA by PCR with the following oligonucleotides: ATAGTTAAACCATCGCCACC (SEQ  
15 ID NO:6) and CTCCATTCGCTCCAAATTCC (SEQ ID NO:7) using AmpliTaq polymerase (Promega) in 1X Taq buffer containing 1.5 mM MgCl<sub>2</sub> for 30 cycles of incubation (94°C x 1 minute, 42°C for 1 minute, and 72°C for 1 minute). The DNA sequence of this fragment was determined, and two oligonucleotides were prepared from an internal portion of this fragment with the following sequence:  
20 AGTCTATCTTACTTTTACTCG (SEQ ID NO:8) and CATCTGAGCAATAAATATTCAC (SEQ ID NO:9). These oligonucleotides were used as probes to screen a human testis cDNA library purchased from CLONTECH (cat #HL1161). Filters were hybridized at 52°C using standard 5XSSC hybridization conditions and washed in 2X SSC at 52°C. Twenty two  
25 clones were isolated that hybridized to both oligonucleotides in a screen of 400,000 clones. DNA sequence was determined from four of the cDNA clones, and all encoded the same novel hematopoietin receptor. The predicted DNA sequence of the full length human receptor chain is shown as SEQ ID NO:3.

30            The human clone was deposited with ATCC as pH25#11pDR2 at accession number \_\_\_\_\_ on February 22, 1996.

Example 2  
Expression of Soluble IL-13bc Protein and  
Assay of Activity

5     Production and purification of soluble IL-13bc-Ig.

DNA encoding amino acids 1-331 of the extracellular domain of murine IL-13bc was fused to a spacer sequence encoding gly-ser-gly by PCR and ligated in frame with sequences encoding the hinge CH2 CH3 regions of human IgG1 of the COS-1 expression vector pED.Fc. IL-13bc-Ig was produced from DEAE-dextran  
10     transfected COS-1 cells and purified via protein A sepharose chromatography (Pharmacia).

B9 proliferation assay

Stimulation of proliferation of B9 cells (Aarden et al. Eur. J. Immunol. 1987. 17:1411-1416) in response to IL-13 or IL-4 was measured by <sup>3</sup>H-thymidine incorporation into DNA. Cells (5 x 10<sup>3</sup>/well) were seeded into 96 well plates with media containing growth factors at varying concentrations in the presence or  
15     absence of IL-13bc-Ig at 1ug/ml. After incubation for 3 days 1uCi/well of <sup>3</sup>H-thymidine was added and the cells incubated for an additional 4 hrs. Incorporated  
20     radioactivity was determined using a LKB 1205 Plate reader.

The B9 cell line proliferated in response to IL-13, IL-4 or IL-6. Only responses to IL-13 were inhibited by the soluble IL-13bc-Ig, indicating that this receptor binds IL-13 specifically, but not IL-4 or IL-6. The tables show cpm. Two  
25     separate experiments are shown.

| cytokine<br>dilution | IL-13<br>(3ng/ml) | IL-13 plus<br>A25-Fc<br>(1ug/ml) | IL-4<br>(20 ng/ml) | IL-4 plus<br>A25-Fc<br>(1 ug/ml) | Cos IL-6<br>(1/10,000) |
|----------------------|-------------------|----------------------------------|--------------------|----------------------------------|------------------------|
| 1                    | 37734             | 1943                             | 6443               | 6945                             | 37887                  |
| 1/3                  | 30398             | 1571                             | 2680               | 2442                             | 36500                  |
| 1/10                 | 16101             | 1461                             | 1767               | 1771                             | 33335                  |
| 1/30                 | 2148              | 1567                             | 1619               | 1783                             | 27271                  |
| 1/100                | 1574              | 1419                             | 1522               | 1576                             | 18831                  |
| 1/300                | 1512              | 1531                             | 1373               | 1577                             | 7768                   |
| 1/1000               | 1316              | 1392                             | 1190               | 1474                             | 2760                   |
| 1/3000               | 1834              | 1994                             | 1482               | 1819                             | 1672                   |

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| cytokine<br>dilution | IL-13<br>(3ng/ml) | IL-13 plus<br>A25-Fc<br>(5ug/ml) | IL-4<br>(20 ng/ml) | IL-4 plus<br>A25-Fc<br>(5ug/ml) | Cos IL-6<br>(1/10,000) | Cos IL-6<br>plus A25-Fc<br>(5ug/ml) |
|----------------------|-------------------|----------------------------------|--------------------|---------------------------------|------------------------|-------------------------------------|
| 1                    | 6413              | 295                              | 1216               | 1158                            | 6969                   | 7703                                |
| 1/3                  | 5432              | 281                              | 518                | 656                             | 7827                   | 8804                                |
| 1/10                 | 2051              | 281                              | 489                | 520                             | 8345                   | 10027                               |
| 1/30                 | 506               | 319                              | 279                | 476                             | 8680                   | 9114                                |
| 1/100                | 430               | 372                              | 288                | 423                             | 7426                   | 10364                               |
| 1/300                | 330               | 287                              | 323                | 420                             | 5531                   | 6254                                |
| 1/1000               | 326               | 389                              | 348                | nt                              | 2524                   | nt                                  |
| no cytokine          | 339               | 279                              | 404                | 394                             | 326                    | 279                                 |

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### Example 3

#### Direct Binding of Soluble IL-13bc to IL-13 Measured by Surface Plasmon Resonance (Biacore Analysis).

5           A Biacore biosensor was used to measure directly the specific binding of  
IL-13 to purified IL-13bc-Ig (Pharmacia, Johnsson et al., 1991). Approximately  
10,000 to 17,000 resonance units (RU) of purified IL-13bc-Ig , human IgG1 or  
irrelevant receptor were each covalently immobilized to different flow cells on the  
sensor chip as recommended by the manufacturer. (RU's are a reflection of the  
10       mass of protein bound to the sensor chip surface.) Purified IL-13 was injected  
across the flow cells at 5 ul/min for 10 mins in the presence or absence of excess  
purified IL-13bc-Ig. Binding was quantified as the difference in RU before and  
after sample injection. Specific IL-13 binding of 481.9 RU was observed only for  
immobilized IL-13bc-Ig whereas coinjection of IL-13 plus IL-13bc-Ig resulted in  
15       no binding to the immobilized IL-13bc-Ig (4 RU). No IL-13 binding was observed  
for either immobilized IgG or IL-11R-Ig (5.4 and 3.7 RU respectively).

| Sample  | IL-13BC-Ig<br>(10,383 RU) | IgG control<br>(13,399 RU) | IL-11R-Ig<br>(17,182 RU) |
|---|---------------------------|----------------------------|--------------------------|
| 100 ng/ml human IL-13                         | 481.9 RU bound            | 5.4 RU bound               | 3.7 RU bound             |
| 100 ng/ml human IL-13 +<br>soluble IL-13BC-Ig | 4.0 RU bound              | not tested                 | not tested               |

#### Example 4

##### Binding of IL-13 Expressed in COS Cells to

##### Labeled IL-13BC-Ig Fusion Protein:

##### COS in situ Detection of IL-13 with IL-13bc-Fc

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Expression vectors for IL-13, IL-4, IL-11 or empty vector were transfected into COS-1 cells in duplicated plates via the DEAE-dextran method. Two days after transfection cells were washed twice in phosphate buffered saline (PBS) and fixed in the culture dish for 10' at 4° C with methanol. Following fixation cells were washed twice with PBS then rinsed once with binding buffer (PBS, 1% (w/v) bovine serum albumin, .1% (w/v) sodium azide) and incubated for two hours at 4° C in binding buffer with IL-13bc-Fc at 1.0ug/ml or with relevant anti-cytokine antisera. Cells were washed twice with PBS and incubated at 4o C with shaking in alkaline phosphatase labeled Rabbit F(ab)2' anti-human IgG diluted 1:500 in binding buffer (for Fc fusion detection) or Rabbit F(ab)2' anti-rat IgG (for anti-cytokine detection) . Cells were again washed twice in PBS. Alkaline phosphatase activity was visualized using nitro blue tetrazolium and 5-bromo-4-chloro-3-indolyl-phosphate.

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Specific binding was visualized under the microscope. Only cells transfected with IL-13 showed specific binding to IL13bc-Ig. (see photo of transfected cells, the Figure).

#### Example 5

##### Other Systems for Determination Biological Activity of IL-13bc Protein

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Other systems can be used to determine whether a specific IL-13bc protein exhibits a "biological activity" of IL-13bc as defined herein. The following are examples of such systems.

##### Assays for IL-13 Binding



The ability of a IL-13bc protein to bind IL-13 or a fragment thereof can be determine by any suitable assays which can detect such binding. Some suitable examples follow.

5 Binding of IL-13 to the extracellular region of the IL-13bc protein will specifically cause a rapid induction of phosphotyrosine on the receptor protein. Assays for ligand binding activity as measured by induction of phosphorylation are described below.

10 Alternatively, a IL-13bc protein (such as, for example, a soluble form of the extracellular domain) is produced and used to detect IL-13 binding. For example, a DNA construct is prepared in which the extracellular domain (truncated prior, preferably immediately prior, to the predicted transmembrane domain) is ligated in frame to a cDNA encoding the hinge C<sub>H</sub>2 and C<sub>H</sub>3 domains of a human immunoglobulin (Ig)  $\gamma$ 1. This construct is generated in an appropriate expression vector for COS cells, such as pED $\Delta$ C or pMT2. The plasmid is transiently  
15 transfected into COS cells. The secreted IL-13bc-Ig fusion protein is collected in the conditioned medium and purified by protein A chromatography.

The purified IL-13bc-Ig fusion protein is used to demonstrate IL-13 binding in a number of applications. IL-13 can be coated onto the surface of an enzyme-linked immunosorbent assay (ELISA) plate, and then additional binding sites  
20 blocked with bovine serum albumin or casein using standard ELISA buffers. The IL-13bc-Ig fusion protein is then bound to the solid-phase IL-13, and binding is detected with a secondary goat anti-human Ig conjugated to horseradish peroxidase. The activity of specifically bound enzyme can be measured with a colorimetric substrate, such as tetramethyl benzidine and absorbance readings.

25 IL-13 may also be expressed on the surface of cells, for example by providing a transmembrane domain or glucosyl phosphatidyl inositol (GPI) linkage. Cells expressing the membrane bound IL-13 can be identified using the IL-13bc-Ig fusion protein. The soluble IL-13bc-Ig fusion is bound to the surface of these cells and detected with goat anti-human Ig conjugated to a fluorochrome,  
30 such as fluorescein isothiocyanate and flow cytometry.

### Interaction Trap

A yeast genetic selection method, the "interaction trap" [Gyuris et al, Cell 75:791-803, 1993], can be used to determine whether a IL-13bc protein has a biological activity of IL-13bc as defined herein. In this system, the expression of reporter genes from both LexAop-Leu2 and LexAop-LacZ relies on the interaction between the bait protein, for example in this case a species which interacts with human IL-13bc, and the prey, for example in this case the human IL-13bc protein. Thus, one can measure the strength of the interaction by the level of Leu2 or LacZ expression. The most simple method is to measure the activity of the LacZ encoded protein,  $\beta$ -galactosidase. This activity can be judged by the degree of blueness on the X-Gal containing medium or filter. For the quantitative measurement of  $\beta$ -galactosidase activity, standard assays can be found in "Methods in Yeast Genetics" Cold Spring Harbor, New York, 1990 (by Rose, M.D., Winston, F., and Hieter, P.).

In such methods, if one wishes to determine whether the IL-13bc protein interacts with a particular species (such as, for example, a cytosolic protein which binds to the intracellular domain of the IL-13bc *in vivo*), that species can be used as the "bait" in the interaction trap with the IL-13bc protein to be tested serving as the "prey", or *vice versa*.

All patent and literature references cited herein are incorporated by reference as if fully set forth.